

Amendments to Claims

This listing of claims will replace all prior versions, and listings, of claims in the subject patent application.

Listing of Claims:

Claim 1 (Currently Amended): A method for local and superficial characterization of a turbid medium using the following parameters:

- 1) the refractive index n of the turbid medium
- 2) the absorption coefficient μ_a of the turbid medium,
- 3) the reduced scattering coefficient μ_s' of the turbid medium,
- 4) the phase function parameter $\gamma = (1-g_2)/(1-g_1)$ of the turbid media, where g_1 and g_2 are the first two moments of the Legendre polynomial development of the phase function p ,
the method and comprising the steps of:

- measuring the spatially-resolved reflectance $R(\rho)$ of the turbid medium (ρ being the source-detector distance) ~~using by any means, comprising an illumination beam as a source and an optical detector, which, by using optional signal processing, which may involve filtering and de-convolution operation to correct for the non-zero area of either the illumination source or the detector, allows for the precise determination of the said spatially-resolved reflectance $R(\rho)$,~~
- mathematically processing $R(\rho)$ to compute at least one of the said parameters: n , μ_a , μ_s' , γ and/or the variations, in time and/or space, of at least one of the said parameters: Δn , $\Delta \mu_a$, $\Delta \mu_s'$, $\Delta \gamma$, whereby an “inverse problem”, which comprises ~~consists in~~ extracting the optical coefficients from the spatially resolved reflectance data is solved, and whereby a “direct problem” comprises ~~consists in~~ computing the spatially resolved reflectance from the values of the optical coefficients n , μ_a , μ_s' , γ involved in a model of propagation of the light in turbid medium and whereby the said “model” incorporates a Legendre polynomial development to the second order of the said “phase function”, and

whereby the said “phase parameter” γ is introduced in the computation as an independent parameter.

Claim 2 (Currently Amended): The method of claim 1, wherein said spatially resolved reflectance is measured by a probe comprising at least one optical fiber carrying the light from the source unit to the turbid medium and at least one optical fiber collecting the reflected light and carrying it to the optical detector ~~detection unit~~, whereby the combination of a variety of emitting fibers and of receiving fibers yields a set of distances ρ at which the reflectance $R(\rho)$ is measured.

Claim 3 (Currently Amended): The method according to claim 1, wherein said spatially resolved reflectance $R(\rho)$ is measured for a set of values of ρ , by using a probe composed of optical fibers in any of the following configurations:

- one emitting optical fiber and a set of optical receiving fibers
- a set of optical emitting fibers and one optical receiving fiber
- a set of optical emitting fibers and a set of optical receiving fibers

giving the spatially resolved reflectance $R(\rho)$ at a variety of source–detector distances ρ and wherein the emitting and receiving fibers are arranged in one of the following configurations:

- on a line,
- on crossed lines,
- on a circle,
- on an ellipse,
- on crossed ellipses,
- on a disk, a rectangle, or any surface, as a dense and contiguous arrangement of fibers,
- on any pattern resulting from the combination of the above mentioned patterns.

Claim 4 (Previously Presented): The method according to claim 3, wherein said spatially resolved reflectance is measured by an optical and electronic micro-system

comprising a collimated or focused beam as illuminating source and 1D or 2D arrays of optical detectors.

Claim 5 (Previously Presented): The method according to claim 2, wherein the probe is put into contact with the turbid medium.

Claim 6 (Currently Amended): The method of claim 1, wherein said spatially resolved reflectance is measured by a non-contact system, comprising at least one of the following combination of optical systems:

- a fixed optical system to irradiate the turbid medium with a collimated or focused beam forming the illuminating source and a fixed optical system comprising an imaging system forming the image of the measured area of the turbid medium on a said “optical detector”, which can be formed of 1D or 2D array of optical detectors, whereby ~~this second optical system can be identical to the first one and whereby~~ the array of optical detectors can be ~~either~~ one of the following systems:
 - [[·]] - a set of optical fibers,
 - [[·]] - an optical and electronic micro-system (MOEM),
- a fixed optical system for the collimated beam illuminating source and a scanned optical system for the said “optical detector”,
- a scanning optical system for the collimated beam illuminating source and a fixed optical system for the said “optical detector”,
- a scanning optical system for the collimated or focused beam used as an illuminating source and a scanning optical system for the said “optical detector”.

Claim 7 (Previously Presented): The method according to claim 1, wherein the absorption coefficient μ_a , the reduced scattering coefficient μ_s' and the phase function parameter γ are determined by fitting the measured spatially-resolved reflectance $R(\rho, \mu_s', \mu_a, \gamma)$ to a set of discretized data obtained by using Monte Carlo simulations, or to interpolating functions giving a continuous approximation of the discretized data obtained by Monte Carlo simulations, and whereby said “Monte Carlo simulations” are

based on a photon propagation model comprising a phase function approximated by a Legendre polynomial development limited to the second order.

Claim 8 (Previously Presented): The method according to claim 7, wherein one or more of the following signal processing steps are performed:

- fitting the measured reflectance $R(\rho)$ by the function:

$$m_1 \rho^{m_2} \exp(m_3 \rho)$$

to give the values of the parameters m_1 , m_2 and m_3 , assuming that the expression $R(\rho) = m_1 \rho^{m_2} \exp(m_3 \rho)$ gives a smoothed expression of the spatially resolved reflectance $R(\rho)$,

- computing the slopes $\frac{\partial}{\partial \rho} \sqrt{R(\rho)}$ and $\frac{\partial}{\partial \rho} (\ln R(\rho))$, or any mathematical

combinations of these two latter quantities and $R(\rho)$, from analytical functions using the parameters m_1 , m_2 , m_3 , or by numerical procedures from the expression

$$R(\rho) = m_1 \rho^{m_2} \exp(m_3 \rho),$$

- computing the values of at least one of the said parameters: n , μ_a , μ_s' , γ and/or the variations, in time and/or space, of at least one of the said parameters: Δn , $\Delta \mu_a$, $\Delta \mu_s'$, $\Delta \gamma$ from the relationship between the reflectance intensity $R(\rho)$ and the slope of $\ln R(\rho)$ (denoted $\partial \rho \ln R$), determined at a fixed distance ρ comparable to the transport mean free path, whereby the computation is made from the data obtained by Monte Carlo simulations, provided that said "Monte Carlo simulations" are based on a photon propagation model comprising a phase function approximated by a Legendre polynomial development limited to the second order.

Claim 9 (Previously Presented): The method according to claim 7, wherein the following signal processing steps are performed:

- computing the reduced scattering coefficient μ_s' and the phase function parameter γ by using the following form of the reflectance:

$$R(\rho) = (A(\rho, \gamma, \mu_s') + B(\mu_a, \mu_s'))^2$$

where the function $A(\rho, \gamma, \mu_s')$ and $B(\mu_a, \mu_s')$ depend also on the source sources and detector detectors characteristics, and the refractive index of the sample, and comprising the steps of:

- computing the slopes of the square root of the spatially resolved reflectance $\frac{\partial}{\partial \rho} \sqrt{R(\rho, \mu_s', \mu_a, \gamma)} = \frac{\partial A}{\partial \rho}(\rho, \mu_s', \gamma)$, which depends weakly on the absorption coefficient μ_a for $0.3 < \rho \mu_s' < 5$, for at least two distances ρ ,
- determining the parameters μ_s' and γ by a polynomial interpolation of the data obtained by Monte Carlo simulations, whereby said “Monte Carlo simulations” are based on a photon propagation model comprising a phase function approximated by a Legendre polynomial development limited to the second order.

Claim 10 (Previously Presented): The method of claim 9, wherein the absorption coefficient μ_a is determined by using the equation:

$$\mu_a = h \left[\sqrt{R(\rho, \mu_s', \mu_a, \gamma)} - f(\gamma, \mu_s') \right]$$

where f and h are continuous functions of the parameters ρ , μ_s' and γ that can be approximated by a polynomial interpolation of the data obtained by Monte Carlo simulations, whereby said “Monte Carlo simulations” are based on a photon propagation model comprising a phase function approximated by a Legendre polynomial development limited to the second order.

Claim 11 (Previously Presented): The method according to claim 1, wherein the difference $\Delta \mu_a = \mu_a - \mu_{a0}$ between the absorption coefficient μ_a and a known value μ_{a0} is computed from the quantity $\sqrt{R(\rho, \mu_s', \mu_{a0}, \gamma)} - \sqrt{R(\rho, \mu_s', \mu_a, \gamma)} = B(a') - B(a_0')$, whereby the function $B(a')$ of the albedo a' can be approximated by a polynomial interpolation of the data obtained by Monte Carlo simulations, whereby said “Monte Carlo simulations” are based on a photon propagation model comprising a phase function approximated by a Legendre polynomial development limited to the second order, and

whereby the calculation can be done for a single γ value, because the influence of the phase function parameter and γ in $B(a')$ are particularly weak.

Claim 12 (Previously Presented): The method according to claim 1, wherein the illuminating source is a broadband source or a white light source and the detector unit comprises a spectrograph or any wavelength analysis system to measure the wavelength dependence of at least one of the parameters $(n, \mu_a, \mu_s', \gamma)$.

Claim 13 (Previously Presented): The method according to claim 1, wherein said turbid medium is a biological medium.

Claim 14 (Previously Presented): The method according to claim 1, wherein the measurement and processing is repeated at different locations of the sample, to build images of any one of the said parameters $(n, \mu_a, \mu_s', \gamma)$.

Claim 15 (Previously Presented): An apparatus using the method of claim 1 for local and superficial characterization of a turbid medium,
a) comprising a source, a detection unit, reference means, signal processing means, a probe comprising at least one optical fiber connecting said source unit to the turbid medium and at least one optical fiber connecting the turbid medium to the said detection unit, and reference means
b) where the distance between the source and the detector is close to one transport mean free path.

Claim 16 (Currently Amended): An apparatus using the method of claim 1 for local and superficial characterization of a turbid medium,
a) comprising an optical and electronic micro-system comprising at least one illuminating source, at least one detector, signal processing means and reference means,
b) where the distance between the source and the detector is close to one transport mean free path.

Claim 17 (Currently Amended): An apparatus using the method of claim 1 for local and superficial characterization of a turbid medium,

- a) comprising a collimated or focused beam used as an illuminating source, at least an optical detector for the detection unit, a fixed or scanning optical system for the illuminating source and a fixed or scanning optical system for the said “optical detector”, signal processing means and reference means,
- b) where the distance between the source and the detector is close to one transport mean free path.

Claim 18 (Previously Presented): A system comprising three apparatus described in claim 15, and characterized by the fact that the distance between the collimated or focused optical beam used as illuminating source and the emitting point connected to an optical detector varies from 0.1 to 2mm. for application to biological media and to turbid media having a transport mean free path similar to biological media.

Claim 19 (Previously Presented): A test, where the control of the homogeneity of the sample over the probed area is performed with the apparatus of 15, which can be carried out according to the following procedure: in the apparatus, disposing two illuminating fibers symmetrically in regard to the collecting fibers; comparing the reflectance curves for each illuminating fiber to detect the heterogeneity of the investigated region or obstructions beneath the fibers; and, if the two curves are sufficiently close, validating the measurement and calculating the average of the two curves.

Claim 20 (Previously Presented): A calibration and normalization procedure, which are carried out with the apparatus of claim 15, whereby the following steps are performed:

- 1) in order to perform relative intensity measurements, the differences of transmitted intensity between each fiber for the apparatus of claim 15 are determined by performing a measurement on a turbid phantom illuminated uniformly or a diffusing sphere of perfectly uniform properties;

2) in order to perform absolute intensity measurements, a calibration performed on a turbid medium of known optical properties, which can be realized according to any one of the following recipes:

- a) solid or liquid turbid medium which properties have been measured by other techniques, or reported in the literature,
- b) water suspension of micro-spheres of known size distribution and refractive index.

Claim 21 (Previously Presented): The method according to claim 4, wherein the optical and electrical micro-system is put into contact with the turbid medium.

Claims 22-41 (Canceled).